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Classification of geothermal resources in Turkey by exergy analysis

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Abstract

The investigations have been directed to technology development in the usage of natural resources as a result of increase in the world energy demand associated with environmental factors. It has also sparked interest in the scientific community to take a closer look at the energy conversion devices and develop the new techniques to better utilise the existing limited sources. Geothermal resources have a great importance for the energy potential in Turkey. Exergy of a system is the capability of doing work and exergy values of geothermal resources are the strongest criterion for determining the system efficiency. In this study, geothermal resources in Turkey have been classified based on specific exergy rates (SER). The computed results of exergy analysis can be used as a tool for evaluating the characteristics of resources, and the optimum application area of geothermal resources can also be defined.

Keywords: Geothermal resources; Exergy analysis; Availability; Renewable energy

Contents

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Nomenclature

h	specific enthalpy (kJ/kg)
s	specific entropy (kJ/kgK)
T	temperature (K)
P	pressure (kPa)
SER	specific exergy rate (dimensionless)
Ψ	specific exergy (kJ/kg)

Subscripts

o	dead-state conditions

1. Introduction

Geothermal energy is the heat of the earth. Since the depths of the earth are very hot, heat flows outward toward the surface and the temperature of the earth increases with depth. The several thermal regimes in the earth give rise to a classification of geothermal resource types which is illustrated in Fig. 1 [1].

Geothermal energy is a domestic resource which contributes to energy security and decreases the trade deficit by displacing imported fuels. It is also environmentally advantageous energy source which produces far less air pollution than fossil–fuel sources. The life of a geothermal resource may be prolonged by re-injecting the waste fluid which is the most common method of disposal [2].

Geothermal resources were classified as low, medium and high enthalpy resources according to their reservoir temperatures which are given in Table 1. Temperature is used as classification parameter due to easy measurement and understanding [3]. The temperature used is the average reservoir temperature measured in exploration wells or

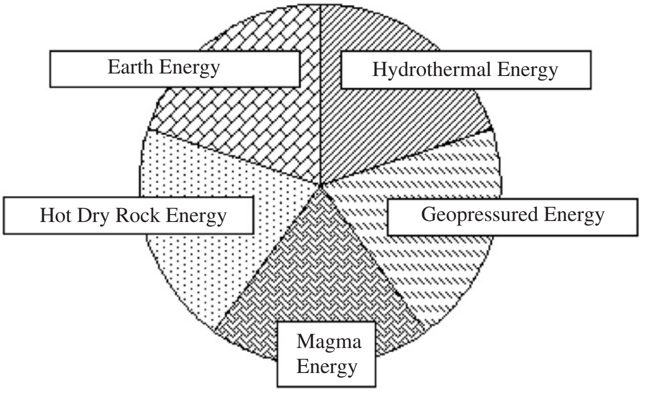

Fig. 1. Geothermal energy types [1].

Table 1
Classification of geothermal resources by temperature [3]

Source	(a) °C	(b) °C	(c) °C	(d) °C	(e) °C
Low	<90	<125	<100	<150	20–70
Medium	90–150	125–225	100–200	—	70–150
High	>150	>225	>200	>150	>150

(a): Muffer and Cataldi [5].
(b): Hochstein [4].
(c): Benderitter and Cormy [6].
(d): Haenal et al. [7].
(e): Anonymous [8].

estimated by geothermometers or other means [4]. However, temperature alone is not a good classification parameter.

The concept of availability or maximum work, available work, available energy or exergy as defined by Rant in 1953 [9], was first introduced by J.W. Gibbs in 1878 [9]. The concept of exergy was first used by Bodvarrson and Eggers [10] to analyse a geothermal power plant. They tabulated the exergy of saturated water for sink conditions of different temperatures. Brook et al. [11] also applied the exergy concept to the geothermal systems for more than 150 °C. The availability of geothermal energy in district heating systems in Bursa, Turkey, was investigated by Can [12]. Geothermal reservoir modelling provides quantitative estimates of future fluid flow from wells exploiting the reservoir. The predicted well performance is determined by the future fluid state (pressure, temperature, enthalpy, entropy, etc.) in the reservoir, and these results are important for the calculation of exergy values. O'Sullivan et al. [13] presented advances and emerging trends in geothermal reservoir simulation techniques. Frifleifsson [14] investigated the geothermal energy utilisation for the benefit of the people. Barbier [15] presented a review of geothermal energy technology and world-wide status of geothermal energy utilisation. Kanoglu [16] carried out an exergy analysis of a dual-level binary geothermal power plant and exergy destruction throughout the plant was illustrated using an exergy flow diagram. Single-flash geothermal power plant in Denizli-Turkey evaluated by using exergy analysis based on actual plant operation data by Cerci [17]. Cerci calculated the exergies of the geofluid at major plant locations and illustrated the exergy destruction from the wellhead to the discharge of steam by using an exergy flow diagram. Koroneos et al. [18] presented a study deal with the exergy analysis of solar energy, wind power and geothermal energy. Renewable and non-renewable energy sources were compared on the basis of efficiency by Koroneos et al. [18]. Mertoglu et al. [19] focused on the direct use of geothermal energy in Turkey. Serpen [20] studied Balçova geothermal system in Turkey. Hydrogeology of the Balçova geothermal field was evaluated and the source of the thermal fluids, recharge area, infiltration rate, location, temperature, pressure and composition of the fluids in the recharge aquifers and geothermal reservoir were described by Serpen [20]. DiPippo [21] evaluated the geothermal power plants by second law of thermodynamics. A methodology was introduced to render the comparison of plant efficiencies on common input and environmental conditions by DiPippo [21]. Geothermal heat pumps offer an attractive option for heating and cooling residential and commercial buildings owing to their higher

energy efficiency compared with conventional systems. Hepbasli and Akdemir [22] presented an energy and exergy analysis of a geothermal heat pump system with a 50 m vertical 1.25 in. nominal diameter u-bend ground heat exchanger. The renewable energy potential of Turkey, the effective utilisation of this potential, energy politics, the political organisations, incentive, pricing and buying mechanism, research and development studies, barriers for development of renewable energy were investigated by Kaya [23]. Kaygusuz and Kaygusuz [24] reported that Turkey is an energy importing nation with more than half of energy requirements met by imported fuels and pollution is becoming a significant environmental concern in the country. In this regard, geothermal energy and the other renewable energy sources are becoming attractive solution for clean and sustainable future for Turkey [24]. Hepbasli and Ozgener [25] presented an overview for geothermal energy utilisation, historical development and opportunities in Turkey. Finally, a thermodynamic optimisation was performed for the Denizli-Kızıldere power plant using real data and most suitable working fluid for the binary cycle were also investigated by Dagdas et al. [26].

In this paper, geothermal resources in Turkey were classified based on the exergy values.

2. Industrial application of geothermal energy

Geothermal energy may be used in a number of ways in the industrial field. Industrial applications include drying, process heating, air-conditioning, evaporation, distillation, desalination, washing and chemical extraction [1]. The most important energy consideration for an industrial complex are the cost, quality and reliability. Geothermal energy may be attractive to an industry providing: (1) the cost of energy per pound of product is lower than that presently used (2) the quality of geothermal energy is as good or better than the present supply and (3) the reliability of geothermal energy is available for the life of the plant. Reliability and availability can only be proven by long-term use or testing.

In some situations, geothermal fluid temperatures which is lower than those required by the industrial applications can be raised by boilers, upgrading systems, heat pumps, etc. In designing geothermal energy recover and utilisation systems, alternative possibilities may be considered for different industrial applications. The usual approach for the utilisation of geothermal fluid by recommended industries is to fit the industry to the available fluids. Alternative approach also requires developing ways to economically improve the quality of available geothermal fluids or the fluids derived from them. Fig. 2 shows the application temperature ranges for some industrial and agricultural applications.

The number of worldwide application of geothermal energy is relatively small while there are many potential industrial uses of geothermal energy. Industrial applications largely require the use of steam or superheated water while agricultural users may use lower temperature geothermal fluids. The largest industrial applications are including pulp, paper and wood processing plant in New Zealand, a diatomaceous earth plant in Iceland and vegetable dehydracation plants in the United States. These systems provide the best present examples of the industrial geothermal energy use [1].

3. Classification by exergy values

When a new geothermal well is discovered, the first thing the explorers do is to estimate the amount of energy contained in the source. This information alone, however, is of little

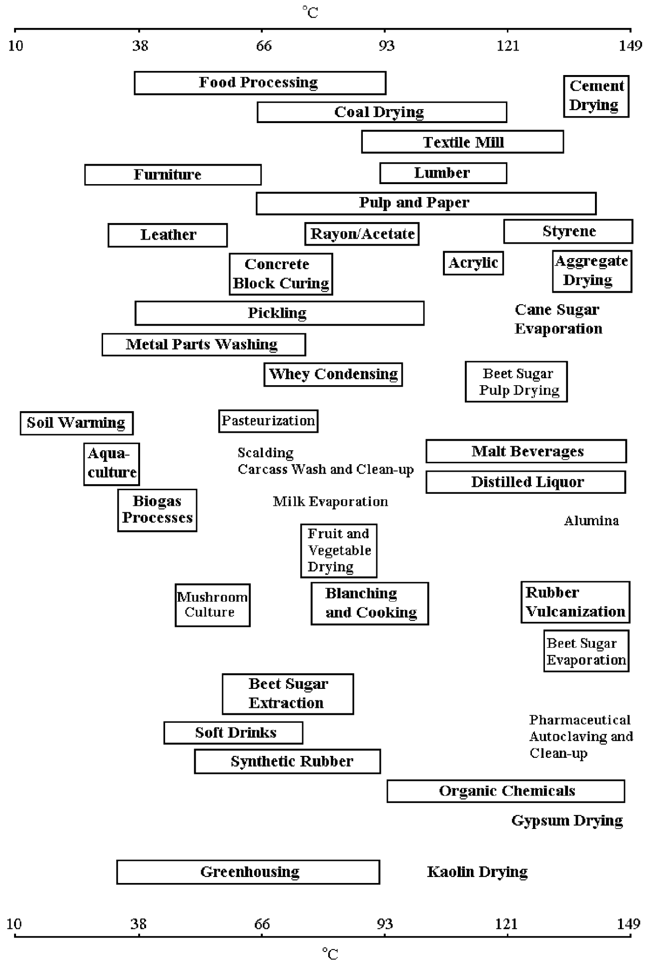

Fig. 2. Application temperature range for some industrial process and agricultural applications [1].

value in deciding whether to build a power plant on that site. In this case, the work potential of the geothermal resource should be known.

The work potential of the energy contained in a system at a specified state is simply the maximum useful work that can be obtained from the system. This situation is described with the availability term. In an availability analysis, initial state is specified and it is not a variable. The system should be in the dead state at the end of the process to maximise the work output [27].

If a system is in a thermodynamic equilibrium with its surroundings, the system is called to be in the dead state. Therefore, it can be concluded that a system will deliver the maximum possible work as it undergoes a reversible process from the specified initial state to the state of its environment, i.e. the dead state. This represents the useful work potential of the system at the specified state and its called availability (exergy). Only one

Table 2
Ψ and SER values for different dead-state conditions

	P (kPa)	T (°C)	s (kJ/kgK)	h (kJ/kg)	Ψ (kJ/kg) triple point	SER (%) triple point	Ψ (kJ/kg) 10 °C	SER (%) 10 °C	Ψ (kJ/kg) 20 °C	SER (%) 20 °C
Triple point	0.6112	0.01	0	0.00	0.00	0.00	0.77	0.00	3.00	0.00
	100	99.632	1.3027	417.51	61.66	0.05	49.42	0.04	38.62	0.04
	1000	179.88	2.1382	762.61	178.54	0.15	157.94	0.14	138.80	0.13
	2000	212.37	2.4469	908.59	240.19	0.20	216.52	0.19	194.28	0.18
Saturated liquid	5000	263.91	2.9206	1154.50	356.71	0.30	328.30	0.29	301.33	0.28
	10000	310.96	3.3605	1408.00	490.05	0.41	457.24	0.40	425.87	0.39
	14000	336.64	3.6242	1571.60	581.61	0.49	546.17	0.48	512.17	0.47
	20000	365.7	3.8765	1734.80	675.90	0.57	637.93	0.56	601.40	0.56
Critical point	22120	374.15	4.4429	2107.40	893.78	0.75	850.16	0.75	807.96	0.75
	20000	365.7	4.9412	2418.40	1068.66	0.90	1020.00	0.90	972.83	0.90
	14000	336.64	5.3803	2642.40	1172.72	0.98	1119.67	0.98	1068.11	0.99
	10000	310.96	5.6198	2727.70	1192.60	1.00	1137.15	1.00	1083.20	1.00
	9000	303.31	5.682	2744.60	1192.50	1.00	1136.44	1.00	1081.86	1.00
Saturated steam	5000	263.91	5.9735	2794.20	1162.48	0.98	1103.50	0.97	1046.01	0.97
	2000	212.37	6.3367	2797.20	1066.27	0.89	1003.66	0.88	942.54	0.87
	1000	179.88	6.5828	2776.20	978.04	0.82	912.98	0.80	849.39	0.78
	500	151.84	6.8192	2747.50	884.77	0.74	817.34	0.72	751.39	0.69
	100	99.632	7.3598	2675.40	665.00	0.56	592.17	0.52	520.82	0.48
Triple point	0.6112	0.01	9.1575	2501.70	0.24	0.00	−90.54	−0.11	−179.88	−0.23

thermodynamic property like temperature or enthalpy is inappropriate to define and classify the geothermal resources. So, the exergy analysis is a powerful tool for the design, analysis and classification of thermal systems like geothermal resources.

Specific exergy, Ψ, is calculated with Eq. (1):

$$\psi = h - h_o - T_o(s - s_o), \tag{1}$$

where h is the specific enthalpy (kJ/kg), s the specific entropy (kJ/kgK), T the temperature (K), and o the dead-state conditions.

Let us take an example of one geothermal fluid at $T = 240\,°\mathrm{C}$, pressure $P = 4\,\mathrm{MPa}$, $h = 1037\,\mathrm{kJ/kg}$, $s = 2.7\,\mathrm{kJ/kg\,K}$ and another $T = 155\,°\mathrm{C}$, $P = 0.5\,\mathrm{MPa}$, $h = 2756\,\mathrm{kJ/kg}$, $s = 6.838\,\mathrm{kJ/kg\,K}$, the first fluid is classified as a high enthalpy resource by its temperature and the second one as an intermediate resource according to its temperature. But, applying Eq. (1), it is clearly observed that the second fluid nearly three times exergetically better than the first fluid. Therefore, describing of geothermal resources by their enthalpies or temperatures alone is inconsistent and confusing. From this point of view, classification of geothermal resources by the maximum work (exergy) values is more consistent and technically meaningful.

In the analysis, specific exergy values are calculated for three dead-state conditions and the results are shown in Table 2. The thermodynamic properties of water are taken from Çengel and Boles [27]. The specific exergy values vary from 0 to 1192.6 (kJ/kg) for triple point conditions. It is obviously clear that the specific exergy values are quite sensitive to sink conditions which vary with location, season and altitude. Therefore, these values are normalised by the maximum exergy value of the corresponding sink conditions. These normalised exergy values are described as specific exergy rate (SER) and vary between 0 and 1 as shown in Table 2. SER values are quite powerful indicator, as they are almost independent of sink conditions. As the enthalpy and entropy values are zero, the triple point is selected as the dead state in the analysis. SER values can be calculated from Eq. (2)

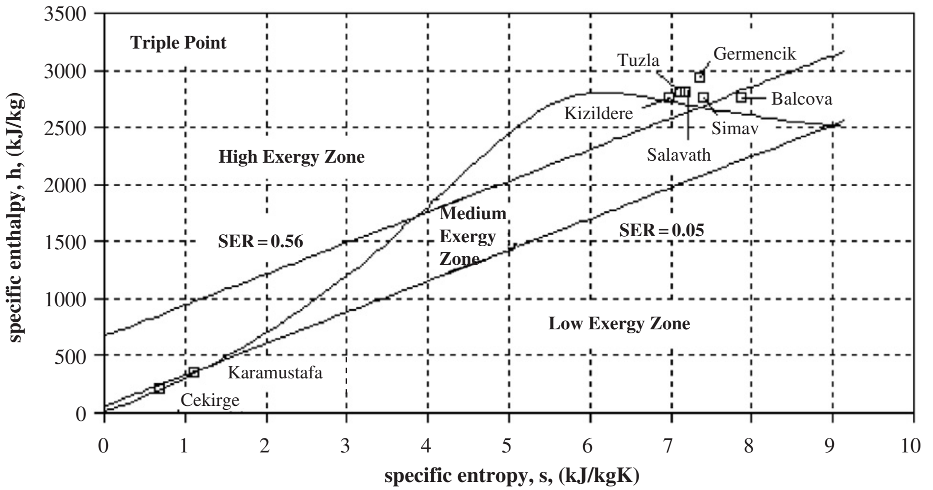

Fig. 3. Classification of geothermal resources by SER values.

for triple point conditions:

$$\mathrm{SER} = \frac{(h - 273.15s)}{1192.6}. \tag{2}$$

A specific enthalpy-specific entropy (h–s) diagram used for classification of some Turkish geothermal resources is shown in Fig. 3. Separation lines is selected discretionary as SER = 0.56 and SER = 0.05. These values are calculated for saturated steam (100 kPa) and saturated liquid (100 kPa), respectively.

A similar classification could be carried out by using specific exergy-specific entropy ($\Psi - s$) diagram as shown in Fig. 4 which is known as Rant diagram.

As shown in Figs. 3 and 4, hot water resources at atmospheric pressure have SER < 0.05 like Çekirge and Karamustafa of which are low exergy resources. SER values of Germencik, Tuzla, Kızıldere, Salavatlı and Simav calculated as over 0.56 and they are plotted at the high exergy zone of the diagrams.

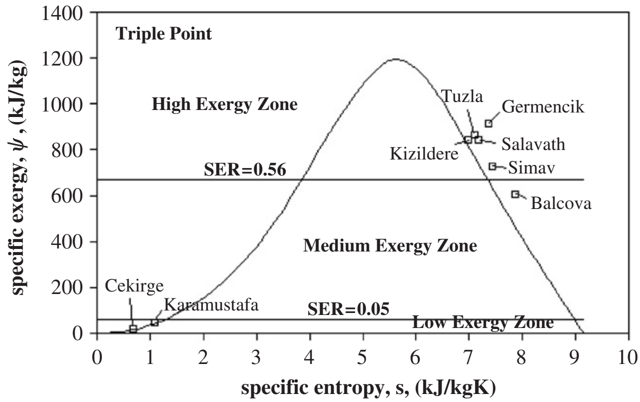

Fig. 4. Classification of geothermal resources by $\Psi - s$ diagram.

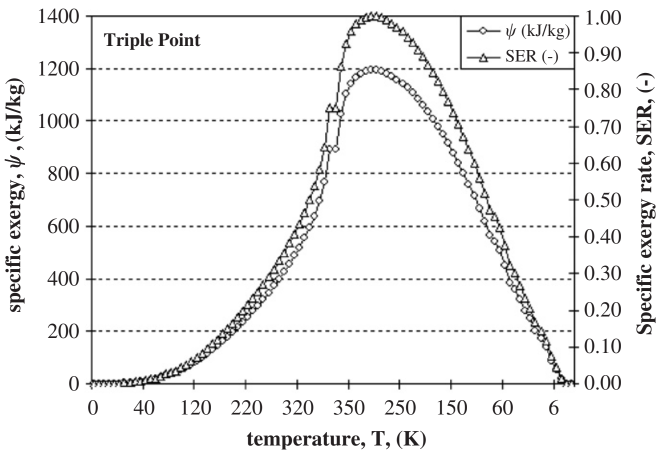

Fig. 5. Variation of Ψ and SER values with temperature.

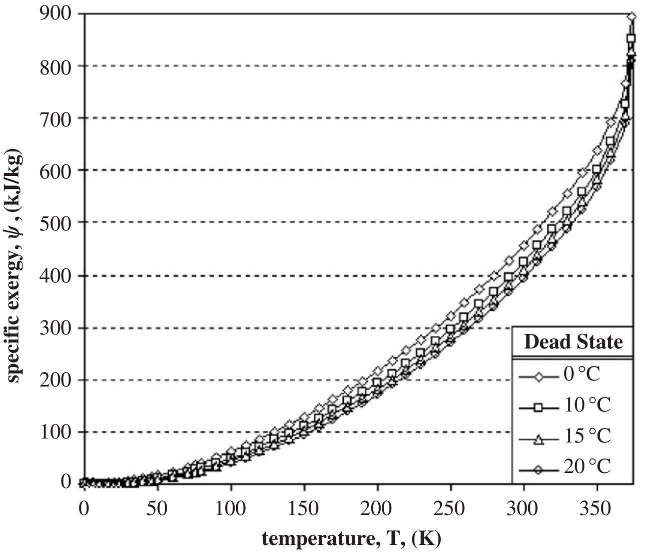

Fig. 6. The effect of dead-state conditions on specific exergy.

Fig. 5 shows the variation of specific exergy and SER with temperature. The temperature range is taken from saturation liquid to saturation steam.

Fig. 6 shows the relation between specific exergy and temperature for various dead-state conditions. It can be seen from Fig. 6 that the specific exergy is increasing with the decreasing of dead state temperatures for the same reservoir temperature.

4. Conclusions

1. Geothermal resources which are environmental friendly and have technical and economical advantageous should be evaluated in order to contribute to energy economy studies in Turkey. Turkey is among the first seven countries in geothermal energy potential. Turkey is located on the Alpine-Himalayan orogenic belt which serves a high geothermal potential. For this reason, the intensive research on application of geothermal resources should be continued specially based on optimisation of energy and source reliability.
2. Classifying of a geothermal resource by its temperature or enthalpy alone can be inadequate because two independent properties are required to define the thermodynamic state of a fluid.
3. On the contrary, maximum useful work or exergy is a much stronger criterion for the categorisation of the geothermal resources. Applying of the second law of thermodynamics to geothermal resources is a consistent base for determining system efficiency, reliability and their classification, like other thermal systems. That kind of exergy analysis could be carried out on condition that determining the source properties like pressure, temperature and flow rate.
4. In the analysis, the triple point of water is selected as the dead-state conditions since the enthalpy and entropy values are zero. SER values of geothermal resources over 0.56 are

classified as high exergy resources, SER < 0.05 low exergy and between of these values are medium exergy resources.

5. The results of exery based classification could be used as the basis of the selection of application area of the geothermal resources. The results of classification diagrams give a better understanding of application of geothermal resources for both academic and industrial users.
6. As it is known that the most important energy consideration for an industrial complex the cost, quality and reliability. Therefore, geothermal energy is attractive to the industrial users.
7. The geothermal energy is renewable kind of energy and it is cheaper than the other source of energies in all respect. It is also does not require high technologies and has zero environmental impact.

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